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Fall and Early Preplant Application Timing Effects on Persistence and Efficacy of Acetamide Herbicides[1]

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Abstract: The persistence and efficacy of acetamide herbicides at application timings from fall to preemergence (PRE) were studied in 1998 and 1999 on mollisols (1.1 to 2.8% organic carbon). Metolachlor, *s*-metolachlor, acetochlor (as an emulsifiable concentrate [EC] formulation and two encapsulated formulations, capsule suspension [CS] and microencapsulated [ME]), and the combination of flufenacet + metribuzin were evaluated at five application times including late fall, 60 and 30 d early preplant (EPP), preplant incorporated, and PRE. Soil bioassays 180 d after application indicated flufenacet + metribuzin, metolachlor, *s*-metolachlor, and the acetochlor CS had 62 to 74% giant foxtail control, whereas acetochlor EC and ME had 43 to 46% control. Applications at 60 EPP of metolachlor, *s*-metolachlor, and acetochlor CS provided 70 to 75% giant foxtail control in greenhouse bioassays, whereas flufenacet + metribuzin, acetochlor ME, and acetochlor EC provided 38 to 57% control. At the 30 EPP timing, metolachlor and acetochlor CS had 80 to 82% control, whereas acetochlor EC provided 46% control, and acetochlor ME, flufenacet + metribuzin, and *s*-metolachlor had 65 to 74% control. Quantitative soil analysis (0 to 6 cm) 10 d after planting (DAP) indicated metolachlor, *s*-metolachlor, and acetochlor CS concentrations ranged from 12 to 16% and 32 to 47% of applied herbicide for the fall and PRE application timings, respectively, whereas acetochlor (ME and EC) were from 1 to 3% and 16 to 21% of applied for the fall and PRE application timings, respectively. Bioassay reduction was correlated ($R^2 = 0.68$) with soil-herbicide concentrations at 10 DAP.

Nomenclature: Acetochlor; flufenacet; metolachlor; metribuzin; *s*-metolachlor; giant foxtail, *Setaria faberi* Herrm. #[3] SETFA.

Additional index words: Soil dissipation.

Abbreviations: CS, capsule suspension; DAP, days after planting; EC, emulsifiable concentrate; EPP, early preplant; ME, microencapsulated; OC, organic carbon; PPI, preplant incorporated; PRE, preemergence; SETFA, giant foxtail.

INTRODUCTION

Acetamide herbicides are usually applied preemergence (PRE) in corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] systems for control of annual grasses and some small seeded broadleaf weeds. Rainfall is required to provide adequate soil solution concentrations of PRE acetamide herbicide to control weeds. Herbicides applied early preplant (EPP) increase the probability of rainfall before weed seed germination and also distribute the seasonal workload for custom applicators and may also eliminate the need for a preplant treatment of paraquat or glyphosate in no-till systems (Stougaard et al. 1984). Because EPP herbicide applications may be subjected to excess rainfall and undergo several dissipation processes, efficacy may be reduced compared with herbicide applications at planting. Annual grasses and small seeded broadleaf weeds usually germinate in the upper 10-cm soil zone (Anderson 1996), thus requiring an adequate herbicide concentration in this zone for weed control.

Persistence of chloroacetamide herbicides is affected by soil organic matter content, microbial degradation, and leaching through the soil profile (Beestman and Deming 1974; Fleming et al. 1992b; Gish et al. 1995; Kotoula-Syka et al. 1997; Weber and Peter 1982; WSSA 1994, 1998). Weber and Peter (1982) concluded that organic matter was the soil constituent most highly related

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

to adsorption of acetamide herbicides, and degradation of these herbicides is typically microbial, with negligible nonmicrobial degradation (Beestman and Deming 1974; WSSA 1994, 1998). Mueller et al. (1999) reported the half-life, based on chemical extractions, of metolachlor on loam and silt loam soils with 1 to 1.2% organic matter to be 13.7 d and half-lives of acetochlor, alachlor, and dimethenamid were 6.3, 6.3, and 7.3 d, respectively. The rapid dissipation of the herbicides was attributed to the effect of warm temperatures in moist soils with low adsorption capacity. These results were similar to those reported by Zimdahl and Clark (1982), who estimated the half-lives of metolachlor and alachlor to be 16 and 11 d, respectively, in a clay loam soil at 20 C and 80% of field capacity. The dissipation of several chloroacetamide herbicides was prolonged under reduced temperatures or soil moisture, but degradation rate was affected more by soil temperature than soil moisture (Petersen et al. 1988). The soil persistence of acetochlor and microencapsulated (ME) alachlor was equivalent to metolachlor (Petersen et al. 1988). Acetamide leaching and adsorption can also be minimized by encapsulation (Davis et al. 1996; Fleming et al. 1992a, 1992b; Petersen et al. 1988; Vasilakoglou and Eleftherohorinos 1997).

The effect of fall and EPP application timing on efficacy and dissipation of flufenacet + metribuzin and ME formulations of acetochlor has not been reported in the literature. A greenhouse bioassay is an effective procedure to determine bioavailability of herbicides in the soil solution (Bunting et al. 2003; Burnside and Schultz 1978; Doub et al. 1988; Zimdahl and Clark 1982). The objectives of this study were to evaluate the persistence and bioefficacy of three formulations of acetochlor (capsule suspension [CS], emulsifiable concentrate [EC], and ME), metolachlor, *s*-metolachlor, and flufenacet + metribuzin when applied in fall and EPP application timings.

MATERIALS AND METHODS

Field Plots. Experiments were conducted at the Northern Illinois Research Farm in DeKalb, IL, and at field locations near Dwight and Annawan, IL, in 1998 and 1999. The soil type at DeKalb in 1998 was a Flanagan silty clay loam (fine, smectitic, mesic Aquic Argiudolls) with 2.2% organic carbon (OC; determined by loss on ignition at 480 C), and in 1999, the soil type was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) with 2.8% OC. The soil type at Annawan in 1998 was a Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudolls) with 1.7% OC and in 1999 was an Elburn silt loam (fine-silty, mixed, superactive, mesic Aquic Argiudolls) with 1.1% OC. At Dwight, the soil type in 1998 was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) with 2.8% OC and in 1999 was a Swygert silty clay loam (fine, mixed, superactive, mesic Aquertic Argiudolls) with 3.2% OC. Metolachor, *s*-metolachlor, flufenacet + metribuzin, acetochlor, and two encapsulated formulations of acetochlor (CS and ME) were applied using a CO_2-pressurized backpack sprayer delivering 187 L/ha of carrier (water) at 220 kPa at rates reported below. Fall application rates were 25% greater than rates used at all other application timings which were metolachlor at 3.50 kg/ha, *s*-metolachlor at 2.25 kg/ha, flufenacet 0.95 kg/ha + metribuzin 0.24 kg/ha (dry flowable 80:20, flufenacet–metribuzin ratio), and all acetochlor formulations at 2.75 kg/ha. Herbicide rates applied 60 and 30 d before planting (EPP), preplant incorporated (PPI) and PRE were metolachlor at 2.80 kg/ha, *s*-metolachlor at 1.80 kg/ha, flufenacet 0.76 kg/ha + metribuzin 0.19 kg/ha, and acetochlor at 2.20 kg/ha. Application dates for all locations are shown in Table 1. All treatments except PRE were incorporated just before planting, and the PRE treatments were applied directly after planting. Shallow incorporation was one pass at a 4-cm depth with a field cultivator. Corn was planted approximately 4 cm deep in 76-cm-wide rows at 71,700 to 76,400 seeds/ha in plots 3.1 (four rows) by 9.2 m long. Soil temperature was measured at 7-cm depth every 2 h from fall herbicide application until 60 d after planting (DAP) using triplicate remote recording devices.[4] Tipping bucket recording rain gauges were used to record rainfall at the research sites. Dicamba was applied post to V-3 to V-4 corn at 0.6 kg ai/ha to control broadleaf weeds. Tillage or mechanical cultivation was not performed on any treatment after planting. Annual grass was rated at 30 and 60 DAP on a scale of 0 to 100% control. Giant foxtail plants in two 0.5-m^2 areas in the middle two rows of each plot were counted at 60 DAP. The experimental design was a randomized complete block with three replications. All data were analyzed using the SAS MIXED procedure (SAS 2000). All possible main effects and interactions were tested. Each year–location combination was considered an environment (Carmer et al. 1989). Environments treated as random variables broaden the possible inference space that conclusions might be applied to (Carmer et al. 1989). Environment and replications (nested within environments)

[4] Hobo Temp, Onset Computer Company, 470 MacArthur Boulevard, Bourne, MA 02532.

effects and interactions were considered random effects; however, other variables (herbicide and timing) were considered fixed effects. Orthogonal linear contrasts were made within the herbicide main effect and the herbicide application timing interaction. Means were separated with the least square means procedure and LSDs were computed at $\alpha = 0.05$. Giant foxtail control ratings were normally distributed and were analyzed as percentages.

Greenhouse Bioassay. Three soil samples (17.7 cm^2 in area and 6 cm deep) were collected between the middle two rows of each treated plot 10 d after corn planting for use in greenhouse bioassays and soil extractions. The soil was stored in 8-L sealed plastic freezer bags at 0 C until analyzed. Samples were thawed, mixed thoroughly, and placed in triplicate 474-cm^3 pots for nine subsamples per plot. Approximately 300 giant foxtail seeds per pot were planted at 1.25-cm depth. The pots were subirrigated initially and then every 3 to 5 d to provide uniform wetting of the soil. Greenhouse conditions were ambient light (July) and a mean daily temperature of 25 C. After 24 d, aboveground foxtail biomass was harvested, and fresh weights and dry weights were determined. Data were treated statistically the same as the field control data.

Soil Extractions. Subsamples of the field soil bioassay samples were extracted for herbicide quantification. The samples were thoroughly mixed and reduced to <2-mm aggregates with a rolling pin. Approximately 50 g (oven-dry weight equivalent, estimated on the basis of soil water content) were placed in a 250-ml round bottom screw top plastic bottle, and 100 ml of ethyl acetate–acetone (95:5, v/v) was added. The bottles were allowed to shake horizontally for 24 h at room temperature and 150 rev/min. The bottles were then removed and placed in a Sorvall RC-5B Centrifuge[5] and centrifuged for 15 min at 8,000 rev/min. A 20-ml aliquot of the supernatant was transferred to a pear flask and reduced to dryness in a rotary evaporator using a BUCHI 461 Water Bath[6] at 50 C and 93 rev/min. Residue was dissolved and resuspended in 2 ml ethyl acetate, vortexed, and herbicide concentration was determined with a Hewlett Packard Gas Chromatograph 5890A,[7] a Hewlett Packard 7673A automatic injector,[7] and a Hewlett Packard 3396 Series III Integrator.[7] A nitrogen–phosphorus detector was used for metolachlor, *s*-metolachlor, and acetochlor (all for-

[5] DuPont Instruments, 1007 Market Street, Wilmington, DE 19898.

[6] Brinkman Instruments, Inc., 607 Cantiague Rock Road, Westbury, NY 11590.

[7] Hewlett Packard Co., P.O. Box 1000, Avondale, PA 19311-1000.

Table 1. Planting and application dates for the field efficacy study in Annawan, DeKalb, and Dwight, IL, in 1998 and 1999.[a]

	1998			1999		
	Annawan	DeKalb	Dwight	Annawan	DeKalb	Dwight
Application dates						
Fall[b]	November 20 1997	November 20 1997	November 20 1997	November 24 1998	November 25 1998	November 25 1998
60 EPP	March 16 1998	March 16 1998	March 16 1998	March 2 1999	March 2 1999	March 2 1999
30 EPP	April 6 1998	April 6 1998	April 6 1998	March 30 1999	March 30 1999	March 30 1999
PPI	May 4 1998	May 15 1998	May 16 1998	May 3 1999	May 5 1999	May 26 1999
PRE	May 4 1998	May 15 1998	May 16 1998	May 3 1999	May 5 1999	May 26 1999
Planting dates	May 4 1998	May 15 1998	May 16 1998	May 3 1999	May 5 1999	May 26 1999

[a] Abbreviations: EPP, early preplant; PPI, preplant incorporated; PRE, preemergence.

[b] Fall application in the previous year before planting (average of 170 EPP).

Table 2. Cumulative rainfall between herbicide application and soil sampling at 10 DAP for each of the five timings and cumulative rainfall from planting to 30 and 60 DAP at Annawan, DeKalb, and Dwight, IL in 1998–1999.[a]

Application or rating timing	1998			1999			
	Annawan	DeKalb	Dwight	Annawan	DeKalb	Dwight	Average[b]
	mm						
Fall[c]	510	403	442	316	393	317	369
60 EPP[d]	284	236	211	194	230	203	211
30 EPP	226	162	195	184	219	73	130
PRE/PPI[e]	77	11	0	32	79	12	34
30 DAP[f]	96	79	65	47	135	120	103
60 DAP[g]	164	180	143	97	211	204	200

[a] Abbreviations: DAP, days after planting; EPP, early preplant; PRE, preemergence; PPI, preplant incorporated.
[b] Combined 20-yr average for the research sites.
[c] Fall in the previous year before the study.
[d] Days from application to planting.
[e] PPI, PRE-soil surface application after corn planting.
[f] Cumulative rainfall from planting to 30 DAP.
[g] Cumulative rainfall from planting to 60 DAP.

mulations). Flufenacet + metribuzin was not included in this portion of the study. Two microliters of extract was injected for sample analysis. The column used was 30 m long by 0.25 mm inner diameter and contained 5% phenyl, 95% methyl, polysiloxane, DB-5 bonded fused silica of 0.25 μm film thickness. Parameters for the detector were injection temperature of 230 C, detector temperature of 235 C, an initial column temperature of 150 C for 2 min with an increase of 70 C/min to 230 C, air flow of 100 ml/min, hydrogen flow of 3.9 ml/min, and helium carrier flow of 65 ml/min. Standard concentrations curves were developed using technical grade herbicide. Extraction efficiency was greater than 93% for all herbicides, with the exception of ME acetochlor, which was 79%. Herbicide concentration data were converted to kilogram per hectare and corrected for extraction efficiency. Solvent-extracted soil herbicide concentrations are expressed as percent of applied herbicide.

Experimental design for the herbicide extractions was similar to the field control and bioassay portion of the study and also included two subsamples per soil sample, resulting in 18 data for each treatment per study site. All data were analyzed using MIXED procedure of SAS, where years and locations were treated as random environments. Herbicide and application timing were the main effects. Herbicide concentration data derived from solvent extraction were analyzed as transformed (natural logarithm) percentages.

RESULTS AND DISCUSSION

Giant Foxtail Control in Field Experiments. Corn was planted <10 d after the target date with respect to 60 and 30 EPP treatments except for at Dwight, IL, in 1999, where planting was delayed 30 d by wet soil conditions (Table 1). Cumulative rainfall after herbicide applications was also fairly consistent across our research sites (Table 2). An average of only 4 cm of rain fell between the 60 and 30 EPP applications, with only the Dwight 1999 environment receiving over 10 cm during this time period. Average temperatures were below 10 C for all environments from the time of herbicide application through March (Table 3). Herbicide and application timing (main effects) significantly affected ($P < 0.05$) giant foxtail (SETFA) control at 30 DAP (Table 4). At 60 DAP, application timing was the only significant factor ($P < 0.05$) associated with SETFA control. SETFA densities in the field were the least sensitive measurement of herbicide efficacy probably because they do not take into consideration overall biomass reduction incorporated into visually estimated control ratings. The only significant difference revealed by orthogonal linear contrasts and SETFA control means (Table 5) was that the encapsulated acetochlor formulations (CS and ME) were superior to acetochlor EC in controlling SETFA at 30 and 60 DAP (Table 4). This finding supports the current use label for acetochlor EC that does not recommend EPP application. Both acetochlor CS and acetochlor ME provided similar SETFA control in the field (Table 4) as did both metolachlor and *s*-metolachlor. Flufenacet + metribuzin also provided SETFA control similar to those provided by metolachlor and acetochlor CS (Table 4).

At 30 DAP, there was no difference in SETFA control because of application timing with acetochlor CS and *s*-metolachlor (Table 6). Control ranged from 85% after fall application to 98% after PPI application for the two herbicides (Table 6). SETFA control provided by meto-

Table 3. Monthly average soil temperatures at 7-cm depth at Annawan, DeKalb, and Dwight, IL in 1998 and 1999.

Month	1997–1998			1998–1999			Average
	Annawan	DeKalb	Dwight	Annawan	DeKalb	Dwight	
	°C						
November[a]	3.9	2.2	4.4	8.1	8.3	8.7	5.9
December[a]	−0.6	−1.1	−1.1	2.8	2.8	2.9	1.2
January	−1.1	−0.6	−0.7	−1.2	−1.1	−0.4	−0.9
February	2.8	2.8	4.4	1.1	1.7	1.7	2.4
March	2.8	5.6	9.4	3.3	2.8	2.8	4.5
April	11.1	8.9	7.2	11.1	9.4	10.6	9.7
May	20.6	20.0	19.4	19.4	16.7	16.7	18.8
June	20.6	23.9	23.3	25.0	20.6	23.3	22.8

[a] November and December temperatures are from the first year indicated in the column heading and commenced after fall herbicide applications.

lachlor was greater than 93% at all application timings except fall. SETFA control was similar ($P < 0.05$) between herbicides when applied at 30 EPP or closer to planting, although acetochlor EC and ME were less efficacious than the other herbicides using a $P = 0.10$ mean separation criteria. SETFA control for all herbicides applied at 30 EPP ranged from 82 to 95%. Flufenacet + metribuzin and acetochlor EC applied at 60 EPP or in the fall controlled SETFA 63 to 79%. Acetochlor ME and metolachlor applied in the fall controlled SETFA 30 DAP 74 and 77%, respectively. All herbicides provided similar control 30 DAP within application timings at 30 EPP or at planting (PPI, PRE) (Table 6). At 60 DAP, acetochlor ME and acetochlor EC controlled SETFA less when applied 30 EPP or earlier, whereas the other herbicides showed diminished control at either the 60 EPP or fall application.

Greenhouse Bioassays. The greenhouse bioassay (Table 4) provided greater sensitivity to herbicide and application timing differences (lowest P values) than field measured indices, suggesting a uniform growth environment and seed density gives a more precise test of relative herbicide persistence and efficacy. Herbicide, application timing, and the interaction between herbicide and application timing were all significant factors affecting giant foxtail bioassays (dry weight reductions) of soil collected at 10 DAP (Table 4). Encapsulated acetochlor (CS and ME) provided more SETFA control than EC acetochlor at 10 DAP. Acetochlor CS provided greater control of SETFA than either acetochlor EC or ME. SETFA control with metolachlor, *s*-metolachlor, and acetochlor CS was not significantly different (Table 6). This finding suggests metolachlor, *s*-metolachlor, and acetochlor CS dissipate at similar rates under field conditions. The CS

Table 4. Level of significance for single degree of freedom orthogonal linear contrasts of the combined data and effect of herbicide and application timing on giant foxtail field percent control, dry weight reduction, and field density. Data are combined across six environments (Annawan, DeKalb, and Dwight, IL, 1998 and 1999).[a]

	Foxtail control[b]		Foxtail density[c]	Bioassay, dry weights[d]
	30 DAP	60 DAP	30 DAP	10 DAP
	$P > F$[e]			
Main effects				
Herbicide	0.02	0.06	NS	0.0001
Application	0.002	0.008	0.009	0.0001
Herbicide by application	0.08	0.06	NS	0.02
Herbicide contrasts				
Metolachlor vs. *s*-metolachlor	NS	NS	0.096	NS
Acetochlor CS and acetochlor ME vs. acetochlor EC	0.008	0.02	0.09	0.0001
Acetochlor CS vs. acetochlor ME	NS	NS	NS	0.0001
Flufenacet + metribuzin vs. acetochlor CS and metolachlor	NS	0.10	NS	0.01
Acetochlor CS vs. metolachlor	NS	NS	0.09	NS

[a] Abbreviations: DAP, days after planting; CS, capsule suspension; ME, microencapsulated; EC, emulsifiable concentrate; NS, not significant.

[b] Visually rated percent control of giant foxtail at 30 and 60 DAP in field studies.

[c] Giant foxtail densities/m^2 in the field studies measured at the 30 DAP rating.

[d] Dry weight reduction of giant foxtail grown in soil samples taken from the field studies 10 days after planting and transported to the greenhouse.

[e] $P > F$, probability that tabular F radio exceeds F radio calculated by analysis of variance. $P > F$ values greater than 0.10 are shown as NS.

Table 5. Effects of herbicide and application timing on giant foxtail control at 30 and 60 DAP, giant foxtail counts at 60 DAP, and on dry weights of giant foxtail as a bioassay species grown in soil samples taken from the field plots 10 DAP. Data are combined across six environments (Annawan, DeKalb, and Dwight, IL in 1998 and 1999).[a]

Main effects	Foxtail control[b] 30 DAP	Foxtail control[b] 60 DAP	Giant foxtail density[c]	Bioassay dry weight reduction[d] 10 DAP
	% control	% control	plants m^{-2}	% control
Metolachlor	91	85	18	79
s-Metolachlor	94	87	8	79
Flufenacet + metribuzin	88	80	16	73
Acetochlor (CS)	92	86	7	83
Acetochlor (ME)	88	82	11	65
Acetochlor (EC)	81	75	18	58
LSD (0.05)	14	17	28	13
Fall	78	68	32	59
60 EPP	85	77	14	60
30 EPP	90	82	11	70
PPI	96	91	5	85
PRE	98	94	2	90
LSD (0.05)	13	17	26	12

[a] Abbreviations: DAP, days after planting; CS, capsule suspension, ME, microencapsulated; EC, emulsifible concentration, EPP, early preplant; PPI, preplant incorporated; PRE, preemergence.

[b] Visually rated % control based on biomass reduction of giant foxtail compared with untreated checks 30 and 60 DAP.

[c] Sum of two counts of giant foxtail plants per $0.5 m^2$ at 30 DAP, averaged over six environments and three replications. Control plots contained 130 plants/m^2.

[d] Percent of control for dry weight of the aboveground biomass of giant foxtail plants grown in field treated soil in a greenhouse bioassay.

encapsulation appeared to extend the persistence of acetochlor more than the ME formulation.

Herbicides affected SETFA control in 10 DAP soil bioassays at all application timings except the PRE application. All herbicides provided greater than 85% control at 10 DAP when applied PRE (Table 6). Acetochlor EC and ME, PPI had SETFA control of 75 and 76%, respectively, which was slightly less than other PPI treatments. Metolachlor and *s*-metolachlor provided similar giant foxtail control of 62 to 71% at the fall and 60 EPP application timings. At the fall and 60 EPP application timings, acetochlor CS provided the best SETFA control of the acetochlor formulations (74 and 75%, respectively). SETFA control provided by the other formulations of acetochlor (EC and ME) at these early timings decreased to below 50%.

When applied at 30 EPP, acetochlor CS provided greater SETFA control (82%) in bioassays than acetochlor ME (65%) and acetochlor ME provided greater control than acetochlor EC (46%). Metolachlor, *s*-metolachlor, and flufenacet + metribuzin provided 70, 74, and 80% SETFA control, respectively, when applied 30 EPP.

Soil Extractions. Soil herbicide concentrations of metolachlor, *s*-metolachlor and acetochlor CS at 10 DAP ranged from 12 to 16% after fall application compared with 1 to 3% of the other formulations of acetochlor (Figure 1). This relative rank order of soil concentrations was found for all application timings, and soil herbicide concentrations for applications at planting ranged from 32 to 47% for metolachlor, *s*-metolachlor, and acetochlor CS compared with 13 to 21% for acetochlor EC and acetochlor ME. Metolachlor and *s*-metolachlor had similar soil concentrations within application timings, which suggested similar soil-dissipation rates. Similarly, efficacy data and soil extraction data both demonstrate the CS formulation of acetochlor has greater soil persistence than the ME encapsulated formulation. The 10 d between PRE–PPI application and soil sampling resulted in the loss of 55 to 82% of the applied herbicide and suggested field dissipation half-lives were less than 10 d for all herbicides. Soil herbicide residues at 10 DAP were not significantly different from the 60 and 30 EPP applications for the same herbicide and formulation. Overall, PRE and PPI treatments provided the best giant foxtail control, and treatments at 30 EPP provided better control than those at 60 EPP or fall applied (Table 6).

Data from field ratings, bioassay of soil samples, and solvent extraction of treated soil suggest the relative order of soil persistence and control of giant foxtail provided by these herbicides is metolachlor = *s*-metolachlor = acetochlor CS > flufenacet + metribuzin > acetochlor ME ≥ acetochlor EC. Regression of quantified herbicide at 10 DAP (Figure 1) vs. bioassay foxtail dry

Table 6. Effects of herbicide and application timing on giant foxtail control at 30 and 60 days after planting DAP, giant foxtail counts at 60 DAP, and on dry weights of giant foxtail 24 and 50 DAP as a bioassay species in soil samples from the plots. Data are combined across six environments (Annawan, DeKalb, and Dwight, IL in 1998 and 1999).[a]

	Application timing				
Herbicide	Fall	60 EPP	30 EPP	PPI	PRE
	% control 30 DAP[b]				
Metolachlor	77	94	95	93	95
s-Metolachlor	91	92	94	96	98
Flufenacet +; metribuzin	76	79	91	96	97
Acetochlor CS	85	89	93	96	98
Acetochlor ME	74	87	83	97	99
Acetochlor EC	63	69	82	95	98
LSD (0.05)			17		
	% control 60 DAP[b]				
Metolachlor	68	88	88	90	92
s-Metolachlor	76	86	87	90	94
Flufenacet +; metribuzin	64	72	79	89	94
Acetochlor CS	76	77	88	93	95
Acetochlor ME	68	81	76	91	93
Acetochlor EC	58	59	73	90	95
LSD (0.05)			14		
	plants m^{-2} 30 DAP[c]				
Metolachlor	59	9	9	8	3
s-Metolachlor	14	13	6	3	2
Flufenacet +; metribuzin	46	13	11	7	1
Acetochlor CS	17	12	4	2	1
Acetochlor ME	19	9	21	3	1
Acetochlor EC	37	28	17	4	2
LSD (0.05)			28		
	% of bioassay dry weight reduction 10 DAP[d]				
Metolachlor	6	71	80	90	93
s-Metolachlor	66	70	74	92	93
Flufenacet +; metribuzin	64	57	70	86	89
Acetochlor CS	74	75	82	91	92
Acetochlor ME	46	51	65	75	87
Acetochlor EC	43	38	46	76	85
LSD (0.05)			13		

[a] Abbreviations: DAP, days after planting; EPP, early preplant; PPI, preplant incorporated; PRE, preemergence; CS, capsule suspension; ME, microencapsulated; EC, emulsifiable concentration.

[b] Visually rated % control based on biomass reduction on giant foxtail compared with untreated checks 30 and 60 DAP.

[c] Sum of two counts of giant foxtail plants per 0.5 m^2averaged over 4 environments and 3 reps. Control plots contained 130 plants m^{-2}.

[d] Percent of aboveground dry weight reduction of foxtail plants grown in field-treated soil sampled 10 d after corn planting and grown for 24 d in a greenhouse bioassay.

weight reduction (Table 6) resulted in % bioassay reduction = 27 + 1.9 (% applied herbicide), with R^2 = 0.68. Petersen et al. (1988) reported the persistence of encapsulated acetochlor (ME) was similar to the persistence of metolachlor in a laboratory incubation study. Acetochlor ME was less persistent in soil than metolachlor in our study, whereas acetochlor EC and ME were found in similar amounts with our solvent extraction procedure. This finding is in contrast to that of Petersen et al. (1988), who found acetochlor ME to be more persistent than acetochlor EC, but consistent with

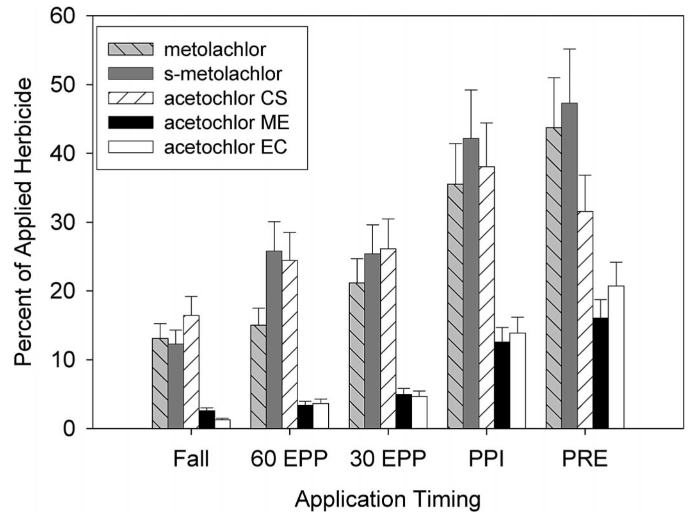

Figure 1. Soil herbicide concentrations (expressed as percent of applied herbicide) 10 d after planting of 0- to 6-cm depth soil samples taken for five application timings at Annawan, Dekalb, and Dwight, IL, in 1998 and 1999. Data are the means of 36 samples. Bars indicate standard errors of the mean.

other studies where EC and ME alachlor had equivalent persistence in field studies (Johnson et al. 1989; Petersen et al. 1988; Vasilakoglou and Eleftherohorinos 1997). In conclusion, metolachlor, *s*-metolachlor, acetochlor CS, and flufenacet + metribuzin were the most effective herbicides for EPP application–timing environment.

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